

EVOLUTION OF ARGOMA SHRUBLAND (*ULEX GALLII* PLANCH.) AFTER CLEARING AND BURNING TREATMENTS IN SIERRA DE ARALAR AND BELATE (NAVARRA)

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ABSTRACT. *Shrub encroachment is considered one of the greatest threats in the conservation of pastures, especially in abandoned territories and territories with low stocking density. However, in the Navarra Pyrenees and Basque mountains, with a high stocking density maintained during the last decades, the expansion of argoma shrubland (Ulex gallii), shows that grazing is not enough for its control and requires evaluating measures of clearing. To evaluate the efficiency of the burning and the mechanical clearing (with two treatments: at ground level and 10 cm above ground) in the control of the shrub, these treatments were applied in different plots of encroached grasslands in two pastoral territories (Sierra de Aralar and Belate). After the burning and clearing, the evolution of the shrub was compared in the cleared plots closed to grazing and in their replicas open to it. The results showed differences between the different treatments in both territories that may be related to the initial coverage of the shrubland. In general, burning was less effective in controlling shrubland and allowed a greater resprout than mechanical clearing. No significant differences were found between the two types of mechanical clearing (at ground level and at 10 cm above ground). Finally, grazing caused a delay in the recovery of the shrub in all cases, but it was not able to eliminate the shrubs completely. From the field observations, the opinions of the farmers and the results of similar experiences, some measures for grassland management were collected and discussed to correct or complement the clearing treatments in order to increase their efficiency.*

Evolución del matorral de argoma (*Ulex gallii* Planch.) tras tratamientos de desbroce y quema en la Sierra de Aralar y en Belate (Navarra)

RESUMEN. *La matorralización se considera una de las mayores amenazas en la conservación de pastos, sobre todo en los territorios abandonados o con escasa carga ganadera. Sin embargo, en el Pirineo navarro y los Montes Vascos, la expansión del argomal (*Ulex gallii*), a pesar del mantenimiento durante las*

últimas décadas de una alta carga ganadera, cuestiona dicha causa, muestra que el pastoreo es insuficiente para su control y aconseja evaluar medidas de desbroce. Para comparar la eficacia en el control del matorral de la quema y el desbroce mecánico (con dos tratamientos: a ras de suelo y a 10 cm sobre el mismo), se aplicaron dichos tratamientos en distintas parcelas con pasto matorralizado de dos territorios pastorales (Sierra de Aralar y Belate). Tras la quema y el desbroce, se comparó la evolución del matorral en las parcelas desbrozadas cerradas al pastoreo y en sus réplicas abiertas al mismo. Los resultados muestran diferencias entre los distintos tratamientos en ambos territorios que pueden estar relacionadas con la cobertura inicial del matorral. En general, la quema ha supuesto un freno menor a la matorralización y ha permitido un rebrote mayor que el desbroce mecánico. No hay diferencias significativas en el rebrote del matorral entre los dos tipos de desbroce mecánico (a ras de suelo y a 10 cm). Por último, el pastoreo ha ocasionado un retraso en la recuperación del matorral en todos los casos, si bien no ha conseguido su eliminación. A partir de las observaciones realizadas en el terreno, las opiniones de los ganaderos y resultados de experiencias similares, se recogen y discuten algunas medidas para corregir o complementar los tratamientos de desbroce que pueden servir para aumentar su eficacia.

Key words: shrub encroachment, grassland management, clearing, conservation.

Palabras clave: matorralización, mejora de pastos, desbroce, conservación.

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1. Introduction

Shrub encroachment refers to the process of shrub expansion in different plant communities, affecting their surface occupation, density, cover and biomass, with special damage to the herbaceous plants (Schlesinger *et al.*, 1990). This process has been observed for decades (Allred, 1949) in very different territories, climates, environmental conditions and histories of use (Van Vegten, 1984; Hobbs and Mooney, 1986; Burrows *et al.*, 1990; Elridge *et al.*, 2011), and is now recognized as a “global process” (Liu *et al.*, 2013). The causes to which it is attributed are also heterogeneous and include variations in the concentration of atmospheric CO₂ (Van Auken, 2000; Archer, 2009), global warming (Knapp *et al.*, 2008), cessation or change of frequency in the fire rate (Scholes and Archer, 1997), overgrazing (Coetsee *et al.*, 2008) and changes in land use, including abandonment (Schlesinger *et al.*, 1990; Archer *et al.*, 1995; Van Auken, 2000). Shrub encroachment is identified as one of the greatest threats in the conservation of mesophitic grasslands (Briggs *et al.*, 2005). In southern

Europe, concern for this phenomenon and its link with rural depopulation and the abandonment of traditional practices has been more recent (Pinto-Correia, 1993; Maestre *et al.*, 2009; Lasanta *et al.*, 2009).

In the Navarrese mountains of the Sierra de Aralar and Belate, grazing is ancestral and nowadays there is still a very active livestock with a stable or even increasing stocking density and an intense use of pastures (Remón Aldabe, 2008). In these circumstances, the increase in shrub cover is a major concern for farmers (Alberdi Collantes, 2003), as in other mountains in nearby territories (Fernández-Giménez and Fillat, 2012). This concern exerts increasing pressure to the managers in demand of action measures. The use of pastoral fire, a common practice until two decades ago to stop undesirable shrubs and ferns spread, is currently very restrictively regulated (BON, 2006). It should be noted that the pastures of this territory, except for very small enclaves with abrupt topography and very shallow soils, constitute “secondary communities” maintained by ancestral grazing in the domain of the beech forest. Therefore, the lignification of the vegetation is interpreted, especially in the framework of the legal forms of protection, as an ecological process that traverses the plant succession towards the “climax” forest expected in a large part of the territory (Aseginolaza *et al.*, 1988).

From an anthropocentric perspective, lignification of vegetation shows advantages and disadvantages (Maestre *et al.*, 2003; Lasanta *et al.*, 2009, 2011). Among the first, now evaluated as “ecosystem services” (Hochtl *et al.*, 2005), the protection of the soil from erosion or an increase in CO₂ fixation (Maestre *et al.*, 2003) may be mentioned. In the opposite direction and focused on grazing, shrub encroachment produces a reduction in rangeland area, cover and quality of pasture (Ward, 1990; Calvo *et al.*, 2005; Zarovali *et al.*, 2007) that hampers the movement of livestock and their access to certain parts of the territory. In addition, vegetation thickening (in short, the increase of lignin) is supposed to increase the retention of water resources and the risk of fires (Lasanta *et al.*, 2011) due to its greater biomass. Finally, shrub encroachment can cause a decrease in biodiversity and affects habitats of high conservation interest (Dolman and Sutherland, 1992). In the Atlantic regions, the detraction of water resources and the risk of fire suppose less concern in the management of the territory. On the contrary, the maintenance of grazing is essential for the conservation of the landscape and pastures that, without herbivory, would be relegated to enclaves where the topography and scarcity of soil prevent forest development. In addition, the current socio-economic framework of the territory ensures the continuity of livestock with high demand for grasslands and, consequently, the pressure of farmers demanding action measures.

The efficiency of the “fight against the shrub” treatments (consisting of plant mortality or brake to its young sprouts, together with the regeneration of the herbaceous pastures) (Redhead *et al.*, 2012) depends on the shrub phenological and morphological characteristics (Scholes and Archer, 1997; Verdú, 2000; Maestre *et al.*, 2009) which description requires a detailed spatial and temporal analysis of the plant. Moreover, the evaluation of advantages and disadvantages related

to the management should also be considered in the choice of the treatment. The response of the vegetation after different treatments of clearing has been studied in environments with Atlantic climate and different dominant shrubs, such as *Calluna vulgaris* (L.) Hull, *Cistus* spp., *Erica arborea* L. (Calvo *et al.*, 2005) and in shrubs of argoma (*Ulex gallii* Planch.), mainly to test their effectiveness in fire prevention (Fernández Filgueira *et al.*, 2013).

After evaluating different treatments, several authors have advocated the mechanical clearing to control the negative effects of revegetation in territories with abandonment (Lasanta *et al.*, 2015, 2016). However, the practice of mechanical clearing is expensive in material and workforce and is difficult in areas far away from access roads. The use of fire by controlled burning also depends, for security reasons, on accessibility, although its practice is secular, simpler in cost and personnel, and can be applied to large areas with homogeneous shrub cover (Métailié, 1981). The impact of fire on soils is difficult to evaluate, as it depends on the characteristics of the soil, the fire (intensity and severity) and the vegetation itself (Armas-Herrera *et al.*, 2016; Badía *et al.*, 2017; Alcañiz *et al.*, 2018). In some cases a great risk of erosion has been reported, as in Nadal-Romero *et al.* (2018) who showed that soil loss was three times greater in the burnt plots than in the control plots.

In this framework and on request of the Department of the Environment of the Government of Navarra, several shrub removal treatments were carried out in the pastoral areas of Belate and Sierra de Aralar, with the goal of collecting suggestions for land management. Specifically, the aim was to verify, through field monitoring during successive years, the effectiveness of several treatments in shrub control, the improvement of pastures, the avoidance of erosion and the preservation of plant diversity and plant species with high conservation interest (Lizaur and Gómez García, 2007, 2008; Gómez García *et al.*, 2011). In this work we evaluated the evolution of argoma shrub (*Ulex gallii* Planch.) after burning and clearing treatments and analyzed the effect of grazing on this evolution.

2. The study area

The study was developed in two pastoral territories of the Sierra de Aralar and Belate (Figs. 1 and 2). In the Sierra de Aralar, limestone and sandy materials, marls and sandstones predominate. Many of these limestones have a karstic morphology, where dolines, lapiaces, uvalas and chasms stand out. Despite the predominance of these substrates and due to the deep washing of the soil, the soils are mostly acidic –Eutrochrept associated to Lithic Xerorthent with inclusions of Lithic Xerorthent and Ultic Hapludalf (Iñiguez *et al.*, 1990)– with top horizon pH in the study plots between 4.8 and 5.2. In Belate, siliceous rocks predominate, rich in shales, schists and quartzites that give rise to more acid soils –Xerorthent or Lithic Udorthent and Entic Haplumbrept (Iñiguez *et al.*, 1990)– with top horizon pH in the study area around 4.3.

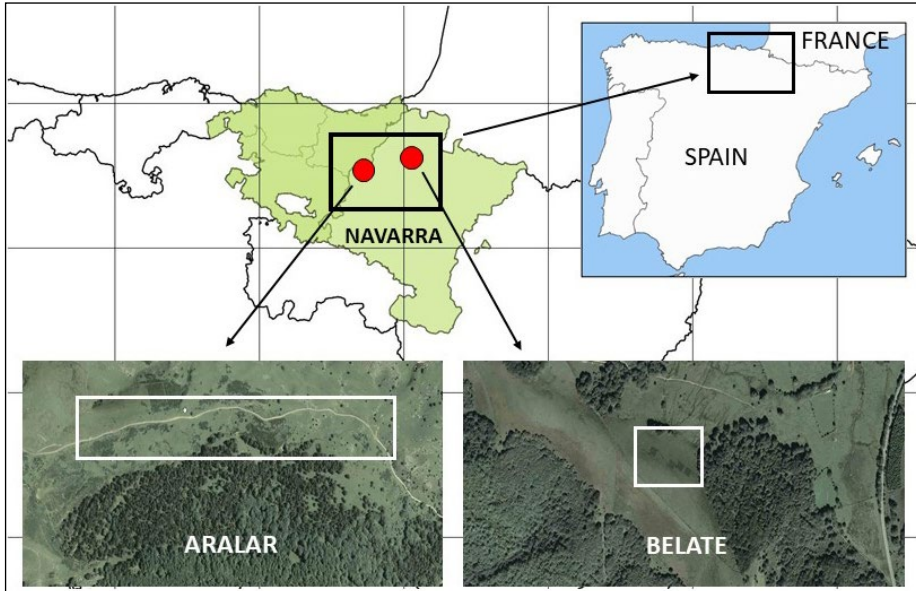


Figure 1. Location of the two study sites (Sierra de Aralar and Belate) in the Pyrenees of Navarra.



Figure 2. General view (on the left) and plot detail (on the right) of Sierra de Aralar (up) and Belate (below) study areas.

Both territories are strongly influenced by the proximity of the Cantabrian Sea, and the E-W disposition of the relief exerts a screen effect to the moisture-laden winds coming from the NW, so in the north-facing slopes fogs and precipitations are frequent, while in the southeast parts climatic continentality increases. The annual precipitations range between 1400 and 2000 mm (ombrotype between wet and hyper-humid) and do not show summer drought. The average temperature ranges between 13 and 14°C. It is possible to differentiate a coline (mesic-temperate) and a montane (over-temperate) belt, with the boundary between both around 600-650 m altitude.

The potential vegetation of the montane belt, in which the study has been carried out, corresponds to the ombrophilous and basophilous Cantabrian beechwoods in Sierra de Aralar (*Carici sylvaticae* - *Fagetum sylvaticae*), and ombrophilous and acidophilous beechwoods in Belate (*Saxifrago hirsutae* - *Fagetum sylvaticae*). The shrub is dominated by the “otea” or “argoma” (*Ulex gallii* Planch.) with some heather (*Daboecia cantabrica* (Huds.) K. Koch, *Erica vagans* L., *E. tetralix* L., *E. cinerea* L. and *Calluna vulgaris* (L.) Hull.) with low plant cover. Forming a mosaic with the shrubs, the predominant pasture in Aralar corresponds to the association *Jasiono laevis-Danthonietum decumbentis* Loidi 1983. The most abundant plants in this pasture are *Festuca nigrescens* Lam. subsp. *microphylla* (Saint-Yves) Markgraf-Danenb., *Trifolium repens* L. and *Agrostis capillaris* L. In Belate, acidophilous pastures of *Agrostis curtisii* Kerguelen (*Carici piluliferae-Agrostietum curtisii* Darquistade *et al.*, 2004) predominate, and *Molinia caerulea* (L.) Moench and *Avenula lodunensis* (Delastre) Kerguelen are very frequent. In addition, patches of megaforbs, birchs and jew trees are found in smaller areas and, especially in Belate, peat bogs and similar plant communities are found in the flooded depressions, where most of the flora with high conservation interest grows.

The main use of both territories is pastoral (around 900 ha of grasslands in Aralar and 270 ha in Belate), with mixed livestock composed of cattle (350 and 176 heads in each territory, respectively), sheep (7600 and 650 heads, respectively) and equine (600 and 74 heads, respectively). This results in a stocking rate (LU, Livestock Unit) between 1.3 (in Aralar) and 2.3 (in Belate) LU / ha (1 LU = 1 cow = 1 equine; 1 sheep = 0.15 LU), which has been stable in the last decade. Cattle graze the area between 180 and 210 days a year (from the middle of May to the middle of October or the beginning of November).

Both territories are, to a large extent, public property and are included in Special Conservation Zones (ZEC). In addition, Aralar has 93% of its territory covered by the “Union of Aralar”, an entity with long tradition and legal personality in force since the 10th century, and recognized in the current legislation of Navarra.

3. Methods

On east facing gentle slopes (slope gradient between 14% and 27%) of Aralar (between 1100 and 1190 m a.s.l.) and Belate (between 915 and 935 m a.s.l.), 16

plots of 20 x 20 m (8 plots in each area) were delimited over uniform vegetation with a shrub mosaic dominated by argoma and pasture of the aforementioned plant communities. The ground was completely covered by vegetation and litter. The experimental protocol responded to three treatments carried out between March and April 2007 by the forestry service of the Government of Navarra: the burning “shrub by shrub” clearing and two mechanical shrub clearing with chains (one at a height of 10 cm above the ground –“at 10 cm”– and another at ground level –“at ground”–). Both in the mechanically cleared and burned treatments, the remains were left on the ground. For each of the three treatments, two contiguous plots were marked in each zone, separated from each other by about 7 m. One was closed with barbed wire to prevent the entry of livestock and the other remained open to grazing (Gómez García *et al.*, 2011). Two additional plots (closed and open to grazing) were marked in a control area with the original vegetation untreated.

The height and coverage of shrub vegetation was measured in three linear transects of 20 m, parallel and equidistant in each plot, with 100 points per transect (one contact every 20 cm). The sampling was carried out just before the burning and clearing treatments and, after the treatments, five times in Aralar and four times in Belate, between 2007 and 2013.

3.1. Statistical analysis

The variables “cover” and “height” of the shrubs were transformed by its elevation to a power, so that its distribution was normal; however, the means of the untransformed variable are shown in the Results section. Normality has been evaluated by the Kolmogorov-Smirnov test, taking into account that the number of observations was 440.

The comparison of means of “cover” and “height” of the shrubs in the burned plots vs. not burned, and grazed vs. no grazed was done with the Student’s test. The comparison of the means over the 7 years of study was done with the Tukey test. The evaluation of the effect of mechanical clearing was carried out using a General Linear Model (PROC GLM, SAS 9.4) with two fixed effects: type of clearing (“at 10 cm” and “at ground”) and time (years before and following the treatment); the differences between the levels (type of clearing and years, respectively) of the fixed effects were evaluated by the Tukey test.

4. Results

4.1. Effect of burning

The shrub coverage did not show significant differences between the burned and unburned plots in the two study areas after the 7 years of treatment (Table 1). With respect to height, only in Aralar there were significant differences between the burned areas and the control ones. In both Aralar and Belate, after the third year of study, it was not possible to distinguish ($p > 0.05$) the cover and height of the shrub from those prior to the action.

Table 1. Means and standard deviation of shrub cover (%) and shrub height (cm) in the burned and unburned plots, in the two study areas –Aralar and Belate– after 7 years of treatment. *t*: Student’s test statistic; *p*: *p*-value.

Zones	Aralar		Probability		Belate		Probability	
	Burned	Unburned	t	p	Burned	Unburned	t	p
Shrub cover (%)	77.02 ± 6.45	80.60 ± 7.36	1.771	0.083	53.15 ± 20.95	58.15 ± 8.88	0.917	0.370
Shrub height (cm)	40.73 ± 22.51	73.55 ± 10.03	5.034	<0.001	36.45 ± 30.26	45.96 ± 8.04	1.066	0.304

4.2. Effect of grazing on burned areas

Grazing on burned plots significantly reduced shrub cover in the two study areas, while no differences in height were observed (Table 2 and Fig. 3).

Table 2. Means and standard deviation of shrub cover (%) and shrub height (cm) in the burned plot under grazing and no grazing conditions in the two study areas –Aralar and Belate– after 7 years of treatment. *t*: Student’s test statistic; *p*: *p*-value.

Zones	Aralar		Probability		Belate		Probability	
	Grazed	Ungrazed	t	p	Grazed	Ungrazed	t	p
Shrub cover (%)	66.07 ± 17.19	78.85 ± 7.09	4.667	<0.001	37.07 ± 19.51	55.85 ± 15.59	4.498	<0.001
Shrub height (cm)	67.21 ± 23.44	58.24 ± 23.59	-0.564	0.123	37.03 ± 21.19	39.78 ± 24.91	0.351	0.728

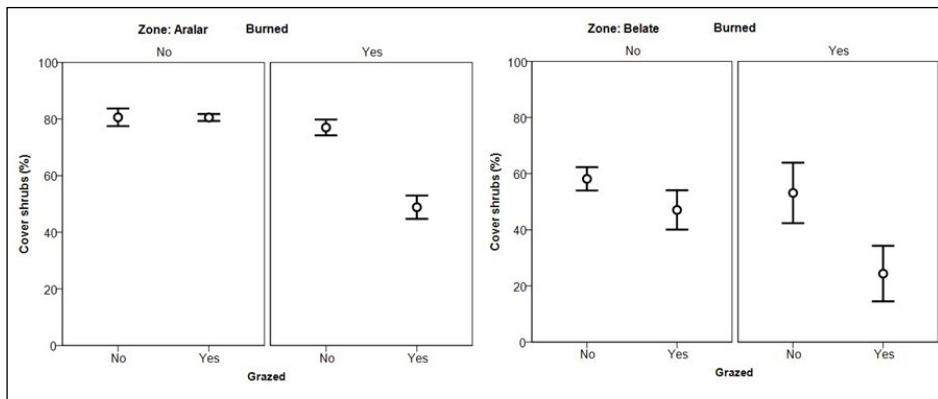


Figure 3. Confidence interval at 95% of the shrub cover in the burned and control plots under grazing and no grazing conditions after 7 years of treatment in Aralar and Belate.

4.3. Effect of mechanical clearing

Mechanical clearing showed a significant effect on both cover and shrub height in the two study areas (Table 3). In terms of cover, the cleared plots “at ground” level showed

a significantly lower value than the cleared “at 10 cm” and the control plots, while the “at 10 cm” plots showed a significantly lower coverage than the control plots. Regarding height, in Aralar, the “at ground” and “at 10 cm” plots showed a significantly lower height than that observed in the control plots, but there were not significant differences between them; in Belate, the “at ground” plots showed significantly lower heights than the “at 10 cm” and “control” plots, and the “at 10 cm” plots showed significantly lower heights than the control plots.

Table 3. Least square means of shrub cover (%) and shrub height (cm) in the control and mechanically cleared plots in the two study areas –Aralar and Belate– after 7 years of the treatment. SED: standard error of the difference of means; p: p-value. For coverage: R^2_{ad} Aralar = 0.872; R^2_{ad} Belate = 0.534; for height: R^2_{ad} Aralar = 0.879; R^2_{ad} Belate = 0.858. Different letters indicate significant differences ($p < 0.05$).

Zones	Aralar			Probability		Belate			Probability	
	Control	At 10 cm	At ground	SED	p	Control	At 10 cm	At ground	SED	p
Shrub cover (%)	84.38c	43.64b	32.65a	3.11	<0.001	52.92c	43.08b	37.18a	3.00	<0.001
Shrub height (cm)	78.11b	37.65a	33.57a	3.46	<0.001	46.17c	30.05b	25.82a	2.67	<0.001

The effect of the time elapsed during the study was significant in both coverage and shrub height (Table 4 and Fig. 4). Regarding coverage, in Aralar, the coverage values tended to increase towards the previous situation although in the seventh year it was still 20% below the previous values; in Belate, in the sixth year the previous coverage was already significantly exceeded. In terms of height, in Aralar, from the fifth year the height of the previous situation was reached whereas in Belate, the previous height was reached in the sixth year.

Table 4. Least square means of shrub cover (%) and shrub height (cm) in the control and mechanically cleared plots in the two study areas –Aralar and Belate– throughout the 7 years of study. SED: standard error of the difference of means; p: p-value. Different letters indicate significant differences ($p < 0.05$).

Aralar	Time							Probability	
	Previous	Year 1	Year 2	Year 3	Year 5	Year 6	Year 7	SED	p
Shrub cover (%)	80.00c	36.77b	43.28a	51.39ab	51.72a	-	58.16ab	5.56	<0.001
Shrub height (cm)	55.83b	27.19a	44.51b	54.42b	55.89b		60.82b	5.81	<0.001
Belate									
Shrub cover (%)	44.16a	36.90a	39.91a	45.28a	-	55.72b	-	4.71	<0.001
Shrub height (cm)	42.92c	20.87a	28.33b	31.66b		46.29c		3.86	<0.001

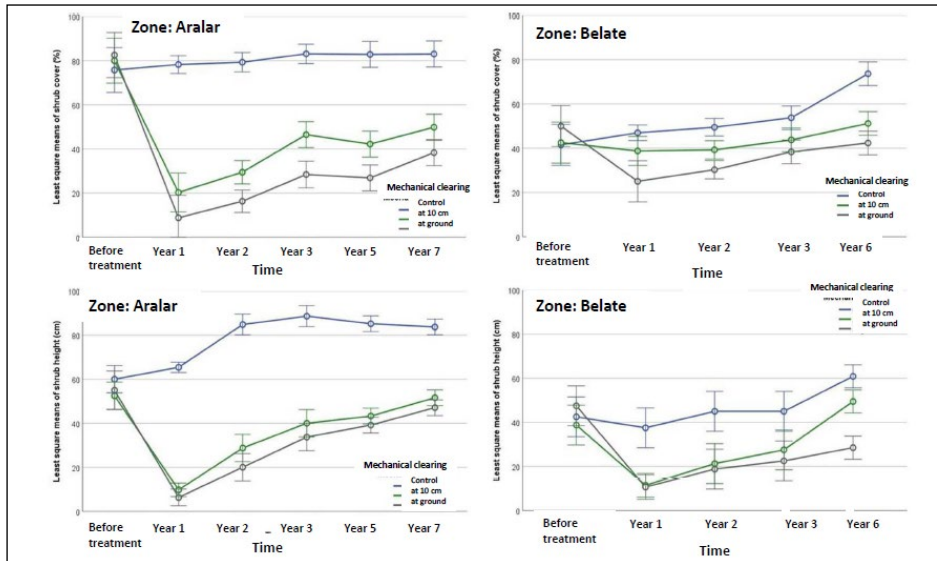


Figure 4. Least square means of shrub cover and shrub height in the control and mechanically cleared (at 10 cm above ground and at ground level) plots in the two study areas, Aralar and Belate, throughout the 7 years of study.

4.4. Effect of grazing on mechanically cleared areas

Grazing on cleared plots significantly reduced cover in the two study areas, but no differences in shrub height were observed (Table 5). On the other hand, the effect of grazing seems to be different according to the original cover (Fig. 5): in Aralar, with a control cover of over 80%, grazing had no incidence, while with a shrub covers under 60%, such as those in “at 10 cm” and “at ground” clearing plots in Aralar, and all the plots in Belate, grazing exerted a significant reduction in shrub cover.

Table 5. Means and standard deviation of shrub cover (%) and shrub height (cm) in the mechanical cleared plots under grazing and no grazing conditions in the two study areas –Aralar and Belate– after 7 years of treatment. *t*: Student’s test statistic; *p*: *p*-value.

Zones	Aralar		Probability		Belate		Probability	
	Grazed	Ungrazed	t	p	Grazed	Ungrazed	t	p
Shrub cover (%)	48.58 ± 29.29	61.48 ± 25.47	2.512	0.013	40.26 ± 13.56	49.81 ± 11.58	3.653	<0.001
Shrub height (cm)	54.18 ± 30.35	52.90 ± 25.86	-0.218	0.828	35.15 ± 20.62	31.47 ± 15.09	-0.735	0.466

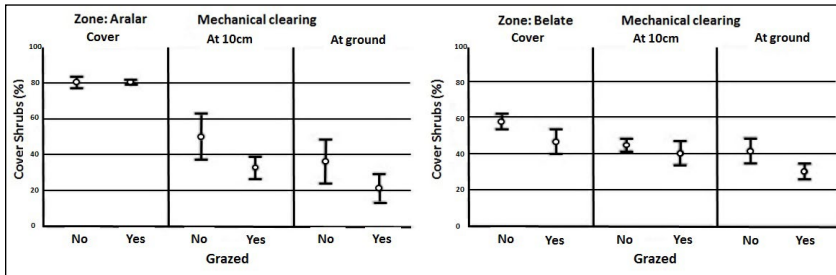


Figure 5. Interval of confidence at 95% of the shrub cover in the mechanical cleared and control plots, under grazing and no grazing conditions, after 7 years of treatment in Aralar and Belate.

5. Discussion

The cessation or reduction of grazing has been proposed as the main cause of shrub encroachment in the Mediterranean region (Zarovali *et al.*, 2007; Maestre *et al.*, 2009). However, in the study area, with a marked Atlantic influence, argoma shrub persists despite the maintenance and even the temporary increase of the stocking rate suggesting that grazing by itself is not enough for stopping shrub expansion, as it has been observed in other nearby Mediterranean mountains (Bartolomé *et al.*, 2000).

After both the burning and clearing treatments, the argoma has shown a vigorous and rapid resprouting capacity from the following spring, exceeding the average value that has been attributed to the species and its congeners in Galicia (Reyes and Casal, 2008). An even more rapid regrowth response for the same species after the same treatments has been described in similar plant and climate communities in Cantabria (Fernández Filgueira *et al.*, 2013), with an average cover recovery of 74% of the initial coverage after two years (after clearing with fire and stripping), and a recovery of the total shrub cover in the same period, close to 95% after clearing with crushing and 99.5% after burning.

Our results showed that the effect of intense grazing results in a temporary delay in shrub recovery, which will be reduced with reduced stocking rates (the usual ones in many nearby territories) that allow the herbivores to select areas with better pasture than those recently intervened. However, clearing seems to attract grazing in all cases and, to the contrary, the (open) control plots have not shown any signs of grazing. On the other hand, initial shrub cover seems relevant for the grazing effect, since grazed plots with less coverage have shown a greater delay in the regrowth.

Both our results and those of similar experiments with the same plant question the efficacy of these treatments in the improvement of pastures in the medium and the long term (Fig. 6). Neither the clearing nor the fire seem to drastically affect the underground organs of the argoma, as shown by its persistence and renewal vigor, together with an abundant post-fire germination of its seeds (Reyes and Casal, 2008). The time of the burning (winter) is the most suitable considering both the protection of the soil (Gehú

and Gehú-Frank, 1960; Montserrat, 1978; Badía *et al.*, 2017; Alcañiz *et al.*, 2018) and the easy combustion of the plant due to the absence of sap circulation. However, the humid and cold soil during this season can provide greater protection for buds and roots (Badía *et al.*, 2017). In addition, the dense structure of the underground organs of the shrub prevents the establishment of herbaceous grass or limits the germination to some annual plants with little pastoral interest and short life after the treatments (Calvo *et al.*, 2002).



Figure 6. Different phases of vegetation succession after shrub clearing.

The resilience shown by the argoma shrub seems to demand a frequent repetition of the treatments, which are not always easy to justify and finance and perhaps are ineffective in the improvement of the pasture if they are not accompanied by other livestock management measures. Considering these uncertainties and based on the observations of the field work and the contrasted opinions of farmers and shepherds (Lizaur and Gómez García, 2007, 2008), we suggest considering the following complementary or corrective measures to improve the treatments:

- (i) The planning of the “pasture demand” in the short and medium term should guide the intensity and frequency of the clearing actions in order to address their economic and ecological justification. In any case, shrub removal should be prioritized in territories with very active livestock (with a stocking rate of at least 1.5 LU / ha in montane pastures with Atlantic climate). With lower

stocking rates, other actions aiming at a better temporal and spatial livestock use (for example, the use of temporary fences or electric shepherds) should be prioritized, focusing on the prevention of new shrub encroachment, as discussed below.

- (ii) Mechanical clearing has shown greater efficacy than fire. The level of clearing “at 10 cm” seems to be sufficient compared to “at ground” level, since the difference in regrowth is minimal. Moreover, its execution is easier and minimizes the risk of soil erosion. As for the periodicity, a clearing repeated annually or every two years could be more effective than a less frequent one as it favors a continuous weakening of the corm. The annual clearing of the zenith regrowths seems advisable, since browsing has not diminished the height growth of the argoma. The effectiveness of a temporary delay of mechanical clearing (not fire!) until the beginning of flowering (in May, shortly before the entry of cattle) could be tested since this is the time of the greatest metabolic expense of the argoma and the treatment would be more adverse for its recovery.
- (iii) The treatments should be prioritized in the smaller and lower cover shrub patches (those that form “islands” between the grass), while in the more extensive and dense masses, the treatment could be limited to the margins and to the opening of corridors to facilitate the prowling of the livestock, its transit to the “pastos rasos” and the browse of regrowths that may precede a subsequent more intense clearing.
- (iv) In the recently cleared areas, grazing (with short-term heavy stocking rates) must be intensified immediately, forcing the passage of livestock, its trampling and manuring (for instance, through the supply of salt, water or with temporary closures) to promote breakage or consumption of young shoots. Without this frequency, there will be a risk of favoring the expansion of undesirable grasses for grazing and precursors of shrub recolonization, such as *Brachypodium rupestre* (Host) Roemer & Schultes and *Agrostis curtisii* Kerguélen (Montserrat, 1978).
- (v) The former measure could also be facilitated by intensifying and prolonging the stay of the large cattle during the winter and early spring, when the regrowth of the shrub coincides with a lower supply of herbaceous grass and forces its consumption. The browsing of the young regrowth, which slows the lateral expansion of the argoma, is only noticeable with equine cattle and, to a lesser extent, with rustic cattle (Montserrat, 1996; Osoro *et al.*, 2005). Winter grazing should be excluded in the steepest areas to protect the soil and respect forest regeneration.
- (vi) If mechanical clearing is not possible, it is necessary to reconsider the traditional use of fire (and its rhythms and procedures, different from the current prescribed burns) for the maintenance of pastures and evaluate its usefulness and its adaptation to the new environmental and socio-economic

framework (Metailié, 1981, 2006). In this regard, it must be noted that many mountain pastoral landscapes with remarkable diversity values of habitats and species, now protected by legal frameworks, are the result of an ancestral use of fire that is now severely restricted or even forbidden, perhaps sometimes without sufficient reflection. In any case, the burning should be limited to the winter season, applied with intensity and annual repetition, avoided in summits, ridges or rocky outcrops and limited to the smallest spots that interrupt access to the best pastures, that is to say, those located at the bottom of valleys and slopes with low slope gradient (Montserrat, 1978).

- (vii) Shrub expansion is preceded, in general, by a thickening of herbaceous grasslands belonging to the domain of hard-leaf and little palatable grasses for their content in silica and low pastoral value (mainly *Agrostis curtisii*, *Brachypodium rupestre*, *Avenula lodunensis* and *Molinia coerulea*). Intensifying the stocking rate in areas dominated by these plants, for instance by continuous grazing, encourages their substitution by *Agrostis capillaris*, *Festuca nigrescens*, *Poa* spp., *Trifolium* spp., *Lotus corniculatus* L., etc. and could be an effective and fast measure to improve grasslands (Montserrat, 1988, 1996) and to prevent shrub encroachment.
- (viii) In the most inaccessible patches, reforestation could be carried out with trees of the surrounding forest (*Sorbus*, *Acer*, *Fraxinus*, *Taxus*, *Crataegus*), alternating those of rapid and slow growth, such as ash and yew. The development of trees forming small islets in the pasture will compete with shrub encroachment and will tend to replace it. The trees will offer shade that will attract livestock and will increase the heterogeneity of the landscape and diversity at different scales.
- (ix) Finally, periodic monitoring (for example every 5 years) of the shrubland surface, the grassland structure and its forage quality should be done to guarantee the continuity of the treatments or to adopt the corrections that are considered convenient.

6. Conclusions

Shrub encroachment in the Navarrese mountains of the Sierra de Aralar and Belate has not been caused by a decrease in stocking density, although it could be related to changes in its management. Regarding shrub control, mechanical clearing has shown greater efficacy than burning in delaying argoma shrubs (*Ulex gallii*) recovery. Clearing at ground level has not shown greater efficiency than clearing at a height of 10 cm. This second procedure is simpler and reduces soil movement and the risk of soil erosion. In any case, both treatments, as currently applied, appear to be ineffective in the medium term in reversing the process of shrub encroachment. In the light of our study, it seems advisable to increase the stocking rate locally, extend the grazing period and facilitate the transit of livestock to the best grazing areas.

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